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THE EFFECTS OF RESONANCE ENERGY ABSORPTION IN LOSSY WAVEGUIDE-DIELECTRIC RESONATORS

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ABSTRACT

The effects of a half and total resonance absorption of the input power are studied with the developed qualitative theory and exact numerical models for the case of waveguide-dielectric resonators built on e -plane rectangular lossy-dielectric posts in a rectangular waveguide.

THEORY AND RESULTS

A qualitative theory of the microwave power resonance absorption is developed for lossy waveguide-dielectric resonators (wdrs) operating on a first higher oscillation and loaded with two identical waveguides. The theory is based on the assumption that the s -th natural oscillation of a lossless resonator is characterized by a complex-valued natural frequency, $\omega_s = \omega'_s - i\omega''_s$. The imaginary part ω''_s determines the resonator radiation q -factor, $Q_{s,rad} = \omega'_s / 2\omega''_s$. Assuming that due to introducing the filling losses, the natural frequency of the above-mentioned oscillation changes as

$$\tilde{\omega}_s = \tilde{\omega}'_s - i\tilde{\omega}''_s = (1 + \alpha_s)\omega'_s - i(1 + \beta_s)\omega''_s. \quad (1)$$

Similar to [1], we succeeded in finding the following formula for calculating the absorption power input with the dominant mode incident from one of the resonator waveguide ports

$$W_L^{(s)} = \frac{2\beta_s}{(1 + \beta_s)^2 (\xi_s^2 + 1)}. \quad (2)$$

In (1), $\alpha_s\omega'_s$ is the frequency shift and $\beta_s\omega''_s$ is the additional attenuation caused by the absorption, $\xi_s = 2\tilde{Q}_s(\omega - \tilde{\omega}'_s)/\tilde{\omega}'_s$ is the resonator detuning parameter. The following expressions for the reflected and transmitted powers of the incident mode have been derived as well:

$$W_R^{(s)} = \frac{\beta_s^2}{(1 + \beta_s)^2 (\xi_s^2 + 1)}, \quad W_T^{(s)} = \frac{\xi_s^2 (1 + \beta_s)^2 + 1}{(1 + \beta_s)^2 (\xi_s^2 + 1)} \quad (3)$$

The parameter β_s can be interpreted as a loss coefficient and the value $\beta_s = 1$ as a critical loss for which the equality of the radiation and intrinsic q -factors is fulfilled. In this case, from (2) – (3) it follows that the maximum absorption $W_L^{(s)} = 0.5$ and the equality $W_R^{(s)} = W_T^{(s)} = 0.25$ are reached at the resonance frequency, $\xi_s = 0$.

The qualitative theory conclusions are confirmed by the results of the exact numerical calculations for the WDRs formed by E -plane rectangular dielectric posts in a rectangular waveguide. It is considered as a section of a partially filled waveguide included into a hollow rectangular waveguide. Three exact algorithms are worked out that allow 1) to synthesize the post geometry according to the required complex-valued natural frequency, 2) to calculate the natural frequency spectrum for the post-resonator with a fixed geometry, and 3) to calculate the full-wave scattering matrix in the TE_{m0} mode basis. These algorithms are based on the mode-matching technique [2].

The special investigations have been carried out for the WDRs operating on the first higher TE_{201} oscillation and providing a single resonance of the 50% absorption of the incident TE_{10} mode power. At first, the lossless WDR geometry providing the given values of the Q -factor and the resonance frequency is searched for using the first above-listed algorithm. Further with the aid of the second algorithm, the value of $\tan \delta$ corresponding to the desired coefficient β_{201} is obtained. The comparative analysis of the exact and approximate WDR responses, illustrated by Fig. 1(a) for the case of the critical loss, shows their good agreement. In Fig. 1 and further, $\kappa = \omega a / 2\pi c$ is the frequency parameter where c is the free-space light velocity, a is the waveguide width. An evident total absorption phenomenon should be waited when two in-phase TE_{10} modes are incident simultaneously from both of waveguide ports. In this case, the structure with the magnetic-wall symmetry occurs. According to [1], the absorption losses in such a structure has to be determined as $W_L^{++} = 2W_L$ where W_L is calculated after the formula (2). The responses in Fig. 1(b) confirm this conclusion. We have found that the loss additivity principle in the form of

$$W_L^+ = \sum_{s=1}^N W_L^{(s)} \quad (4)$$

Is valid if a wdr maintains n natural oscillations in the considered frequency range.

Fig. 1. Rectangular dielectric post responses calculated with the exact (solid curves) and approximate (dotted curves) models in the case of the critical loss, $\beta = 1$. (a) Excitation from one port. (b) Excitation from two ports simultaneously ($t/a = 0.084$, $r/a = 0.051$, $\varepsilon = 50(1 + i0.0285)$).

To realize the condition for the total resonance absorption, one has to operate with degenerated natural oscillations having equal q -factors and the different symmetry along the wdr longitudinal axis.

As an example of a multimode wdr, we will consider the lossless dielectric post with $t/a = 0.217$, $r/a = 0.514$, and $\varepsilon' = 15$. The location of the complex-valued eigenfrequencies of its TE_{m0n} natural oscillations is shown in fig. 3(a) by empty circles. We see that TE_{301} and TE_{204} oscillations of the different symmetry have the coincide eigenfrequencies $\kappa'_{301} \approx \kappa'_{204} = 0.941$. In the vicinity of this point, a total transmission is observed in the scattering problem (see the dashed-dotted curve in fig. 3(b)).

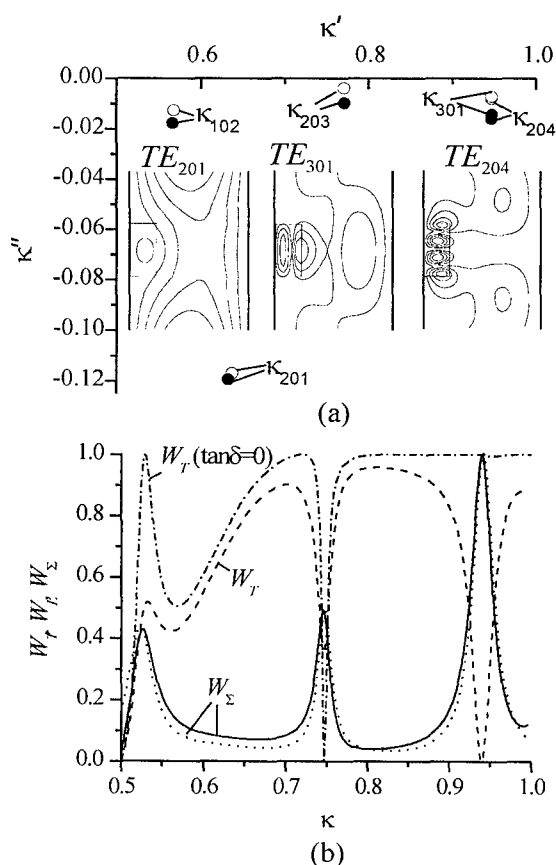


Fig. 3. (a) Location of the eigen-frequencies in the complex plane κ for the lossless and lossy dielectric posts. (b) Frequency responses of the lossless and lossy posts.

REFERENCES

- [1] L.A. Vainshtein, *Electromagnetic Waves*, Moscow, Radio i Svyaz Publ., 1988 (in Russian).
- [2] L.B. Minakova and L.A. Rud', "A spectral approach to the synthesis of dielectric waveguiderejection resonators," *Journ. Telecommun. Techn. Electronics*, V. 47, No 5, 2002, pp. 507-512.

Further, we have found the value of $\tan \delta = 0.0183$ providing the critical loss for the above-mentioned oscillations. The eigen-frequency location for the lossy dielectric post is presented in Fig. 3(a) by black circles. The exact responses of the transmitted and absorbed power for the lossy post are shown in Fig. 3(b) by the dashed and solid curves, respectively. The effect of a practically total absorption is realized at the point $\kappa = 0.940$.

To verify the validity of the loss additivity principle (4), we have calculated the loss coefficients β_{m0n} for all the oscillations from Fig. 3(a) and have used them in calculating the dependence $W_\Sigma(\kappa)$ with using (2) and (4) (see the dotted curve in Fig. 3(b)). We can conclude that the representation (4) gives very exact results elsewhere over the single-mode waveguide range if the values of β_{m0n} and ξ_{m0n} are exactly defined for all the natural oscillations taken into account during the calculations.